Environmental Effects of the No Action Alternative for Salton Sea
Limnology and Fisheries

Doyle Stephens, USGS, July 28, 1999

The effects of a "no action alternative" on the limnology and fishery of the Salton Sea under three annual inflow scenarios (current or 1.3 million ac.ft., 1.0 million ac.ft., 0.8 million ac.ft) include increases in salinity and decreases in elevation of the Sea. Under all three inflow regimes the Sea will become more saline and it will become smaller. The rate at which this happens and the final elevation and salinity is dependent on the average annual inflow into the Salton Sea.

Changes in the water chemistry of the Salton Sea are due to changes in solubility (mostly reduction) as salinity increases and changes in the biological community which cause secondary effects on the water chemistry. For some constituents such as dissolved oxygen, increasing salinity will result in a reduction in absolute oxygen concentrations but this may be partially offset by reductions in the water depth which would increase the depth of mixing of atmospheric oxygen. The amount of oxygen dissolved in water has important biological consequences and is inversely proportional to the salinity. At 1 atmosphere of pressure, water temperature of 10° C, and salinity of 40 ppt (41.6 g/L), oxygen saturation is 8.84 mg/L. Under the same temperature and pressure but a salinity of 60 ppt (63.6 g/L), oxygen saturation is reduced to 7.77 mg/L, and at a salinity of 100 ppt (110 g/L) it is 5.95 (Sherwood et al., 1992). Note that salinity is often expressed in ppt (parts per thousand) by weight as well as g/L which is a weight per unit volume expression where volume is 1 liter. Since a liter of hypersaline water weighs more than 1000 g, the greater the salinity, the greater the disparity between salinity expressed as ppt and as g/L. A salinity of 44 g/L expressed as weight per weight would be 44 g/1044 g, or 45.9 ppt.

As water surface elevation declines, it becomes progressively easier for wind energy to mix the water column. This could transport oxygen to deeper layers of the water column, and in some areas, to the bottom. Currently during the summer months, 60 to 100% of the lake bottom is exposed to dissolved oxygen concentrations of <1 mg/L (S. Hurlbert, Progress Report 1, June 1999). Increased ease of mixing could facilitate suspension of materials present in bottom sediment which could result in increased oxygen demands for suspended organic material. Increased easy of wind mixing results in increases in local current velocities and the ability to transport plankton and suspended substances. This could increase the rate of movement of phytoplankton in the Salton Sea, speeding up the effects of blooms of toxic algae. Decreased water depth may allow greater suspension of bottom materials that would increase turbidity and could increase the rate of mobilization for sediment-derived nutrients such as nitrogen and phosphorus and further accelerate eutrophication.

Changes in the water chemistry and subsequent changes in biological communities of the lake will have considerable effects on recreational opportunities, fisheries, economic development, and avian and human populations associated with the Salton Sea. Table 1 summarizes potential changes in the water chemistry, associated changes in the biology, and effects on use of the Sea caused by increasing salinity and decreasing depth.

Microcosm experiments done in 1990-91 using Salton Sea water at five augmented salinities at San Diego State University demonstrate what may occur as the Sea becomes progressively more saline (Gonzalez et al., 1998; Simpson and Hurlbert, 1998; Simpson et al., 1998; Hart et al., 1998). Tanks holding 312 liters of Salton water at experimental salinites of 30, 39, 48, 57, and 65 g/L were inoculated with organisms from Salton Sea and followed over a 15 month period to determine changes in the water chemistry and biological communities. Tilapia (1 per tank) were added to tanks at salinities of 39 and 65 g/L to determine the effect of a secondary consumer. Absolute dissolved oxygen concentrations were negatively correlated with salinity and water temperature. After a six month period (apparently needed to mature the individual ecosystems and for bacterial stabilization of organic matter in sediment) oxygen percent saturation showed distinct diel fluctuations and often exceeded 110% indicating considerable algal photosynthesis. While no definitive effect of salinity was observed, the percent saturation values were lowest in the 65 g/L system (Gonzalez et al., 1998). While pH increased abruptly at all salinities during June and July it stabilized but often was 0.2 to 0.3 units higher at salinities of 57 and 65 g/L than at lower salinities.

Phosphorus was mainly present in an organic form. As systems became established, dissolved organic phosphorus and particulate phosphorus tended to be negatively correlated with salinity and were reduced by 30-80% at 65 g/L, relative to lower salinities. Ratios of total nitrogen to total phosphorus were always greater than 16 and reached final values of 23-120, showing increases with salinity and the addition of tilapia. These values suggest phosphorus might have been limiting to algal growth. The authors site studies that in-situ studies done to evaluate sediment-water nutrient interactions generally report an increased release of phosphate and ammonia from sediment that is directly correlated to salinity (Clavera et al., 1990; Seitzinger et al., 1991). The large ratio between total nitrogen and total phosphorus shown in the microcosm study is contrary to that often found in terminal basins with hypersaline lakes. Typically, as the salinity of a lake increases and amount of flushing decreases, the N:P ratio declines and nitrogen becomes limiting to algal production (Caraco et al., 1987; Hecky and Kilham, 1988; Bierhuizen and Prepas, 1985). Nitrogen has been reported as limiting phytoplankton production in Great Salt Lake (Stephens and Gillespie, 1976; Wurtsbaugh, 1988). One difficulty arising from microcosm studies is their small size may artificially influence biological processes and be unrepresentative of the larger natural system.

The microcosm studies showed that changes in the physical and chemical characteristics of water at different salinities were the result of biological activities of the primary producers (algae) as modified by the zooplankton grazers and fish. For example, while silica increased slightly at all salinities, it declined 60-90% at the 65 g/L salinity probably due to abundance of periphytic (attached to substrate) diatoms that utilize silica as part of the cell structure. The large periphyton crop also removed nitrogen and phosphorus so the smallest concentrations of soluble nutrients were present at the highest salinity. The attached diatoms were able to expand their population because phytoplankton were removed from the water column by grazing Artemia and Gammarus and that allowed light to penetrate the water column to the bottom of the tank where it was used by periphyton.

While Artemia are capable of living and reproducing at salinities near 35 g/L, predation and competition by other zooplankton generally limits their abundance at lower salinities. They became abundant in microcosms at a salinity of 57 g/L but large populations of the copepod Apocyclops and amphipod Gammarus developed that fed on

Artemia and eliminated them from tanks with this salinity. Artemia did well at 65 g/L because Apocyclops and Gammarus were limited due to the higher salinity.

Recently, several potentially toxic algae have been found in the Salton Sea. As many of these are marine species, increases in salinity may allow them to expand their numbers. These include *Chatonella* cf. *marina*, a toxic marine alga now present in winter, *Heterocapsa niei*, a potentially toxic dinoflagellate that is often a dominant species, a Pfiesteria-like organism found in 1997, and *Gyrodinium uncatenum* and several species of *Gymnodinium* that may be capable of toxin production (Dexter et al., 1999). *Prymnesium*, a toxic alga was present in SDSU microcosm studies at a salinity of 48-57 g/L and may become more common at higher salinites in Salton Sea.

It should be remembered that species do not abruptly disappear as environmental stresses are gradually increased. Populations fail to reproduce and numbers of individuals gradually decline. Because the decline is slow and at the population level it may not be recognized until the last individual of the population is gone. A excellent review of the salinity tolerances of animals, especially fish inhabiting the Salton Sea is given in Thiery (1999). Data indicate that the covina fishery could fail at any point above the current salinity of 44 ppt (45.9 g/L) and croaker and sargo will disappear if the salinity reaches 50 ppt (52.5 g/L). Tilapia and possibly mullet may still be present at 50 ppt. The pileworm, *Neanthes succinea* is the basis of the Salton Sea food chain and could disappear when the salinity reaches 50 ppt and this may allow amphipods such as *Gammarus mucronatus* to become the dominant benthic invertebrate. At 60 ppt (63.6 g/L), the tilapia likely would disappear leaving only desert pupfish, longjaw mudsuckers and possibly sailfin molly as the only fish. Because these fish are small, they may not fully replace the tilapia as food for fish-eating birds and bird populations could decline. At about 70 ppt (74.9 g/L), the copepod *Apocyclops dengizicus* could disappear leaving only protozoans to graze the phytoplankton. By 80 ppt (86.4 g/L), all fish will be gone. In the absence of fish and predatory zooplankton such as Gammarus and copepods, the zooplankton community will be dominated by brine shrimp (*Artemia franciscana*) and the benthos by brine flies (*Ephydra* sp.).

At salinities in excess of 80 g/L, the primary producers (algae and bacteria) may be limited to halotolerant species of diatom, green algae, cyanobacteria, and possibly photosynthetic sulfur bacteria at even higher salinities. A generalized summary of possible species that may be present within key salinity ranges is given in table 2. While Artemia and Ephydra do well at higher salinities, Artemia is rarely found at a salinity greater than 200 g/L (Kristensen, 1963). Figure 1 shows the highest salinity, given in table 1 of Thiery and converted to g/L, that may be tolerated by each of the fish species. The time period each species will survive is directly related to the volume of inflow which controls the salinity. Under conditions of a mean annual inflow of 0.8 million acre feet, Orangemouth corvina could be gone as early as year 2004. Under the 0.8 and 1.0 million acre feet/year inflows, salinity would reach 92 g/L between years 2023 and 2027 and all fish would be gone. In general, there is little difference in survival times for fish between the two lowest inflow regimes.

Several caveats should be made when interpreting the effects of salinity on organism survival and reproduction. (1) Salinity tolerance from lab studies is based on salt toxicity and associated effects on reproduction to the individual, not the population. (2)Species survival in the environment involves the population, not the individual. (3) It should be noted that for all organisms, the tolerable salinity range is not a plateau which drops off precipitously, but is a slope where stress is gradually placed on the organism and its response represents the cumulative stress not only of salinity, but changing food supplies, temperature, ionic composition and toxins. The greater the cumulative stress, the steeper the slope.

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Summary of Notes

Salton Sea Workshop- No Action Alternative, Effects on Limnology and Fisheries
July 21, 1999
Cal State Poly-Pomona

- Increasing salinity
- Decreasing elevation
- Decreased volume=increased mixing
- Increased littoral zone relative to volume
- Possible increased water temp. in summer; decreased water temp. in winter (tilapia may stop feeding at 15°C.
- Change in bottom substrate
- Increased local current velocities and transport of planktonic forms
- Reduction in buffering as calcium carbonate is lost by precip. Hypersaline water dominated by Na, Mg, Cl, SO4
- Anoxic conditions may keep Se immobile in bottom sediment. However, if mixing creates oxic conditions, result could be similar to Tulare Ponds selenium availability.
- Currently, light penetration sufficient for photosynthesis limited to 3 m. Increased mixing may increase turbidity and mobilize bottom nutrients to water column, resulting in increased turbidity.
- Turbidity could increase with salinity as phytoplankton blooms may increase and zooplankton grazers may not be abundant (see Carpelan in Walker, 1961). How salt tolerant are rotifers and copepods?
- Chatonella, a toxic marine alga now present in winter, may expand at higher salinities.

- Prymnesium, a toxic alga was present in SDSU microcosm studies at 48-57 g/L salinity and may expand at higher salinites in Salton.
- Salinity tolerance from lab studies is based on toxicity and effects on reproduction to the individual, not the population.
- Current salinities allow alga Heterocapsa niei, toxic dinoflagellate, to be abundant in winter.
- Tilapia salinity tolerance may be 120 g/L in lab or perhaps 80 g/L in field. See Whitfield and Blaber (1978).

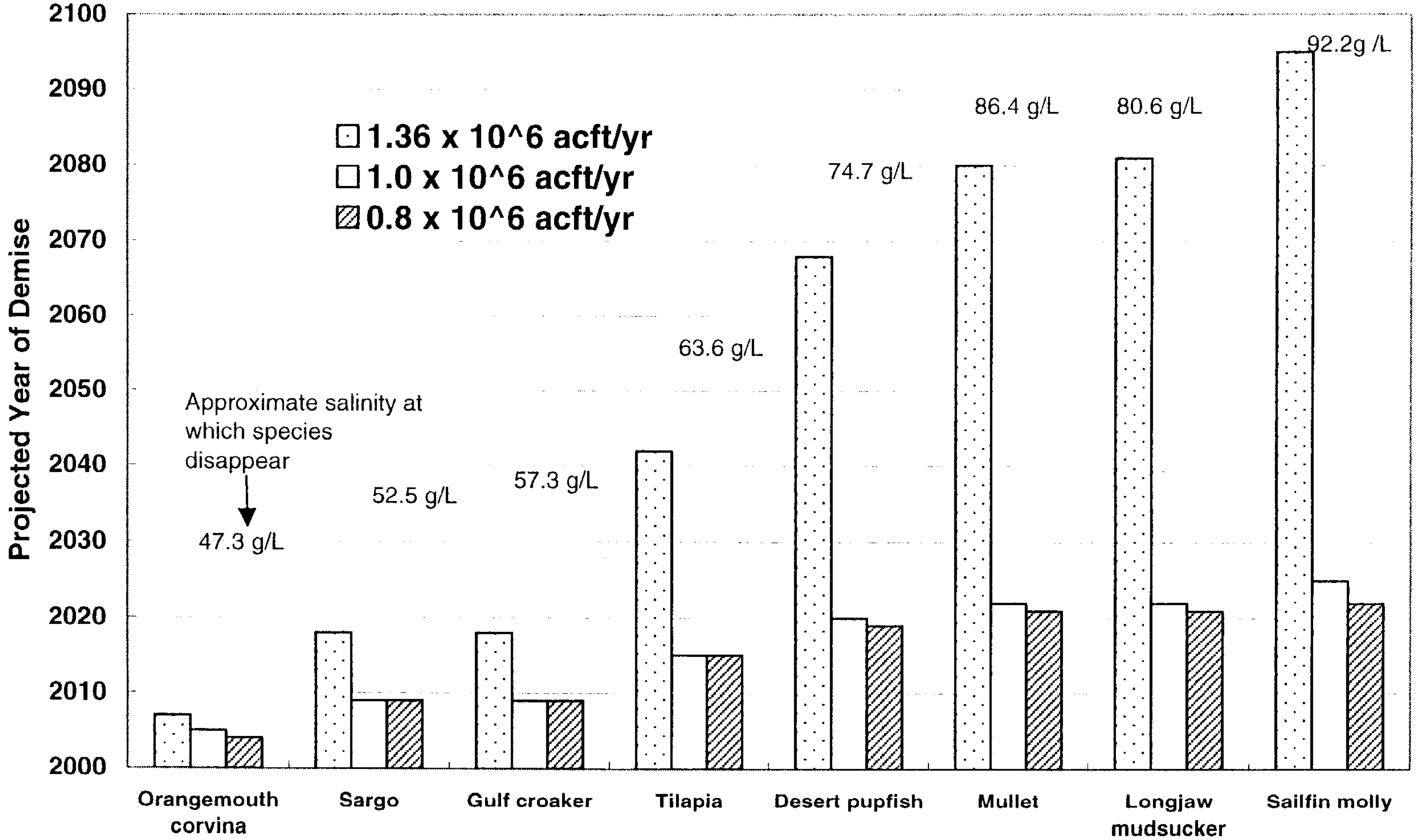

Figure 1.- Comparison of the effects of three alternative inflows of water on salinity of the Salton Sea and projected demise of its fisheries. (Reference Thiery, 1999).

Table 2.- Effects of salinity on biota (exclusive of bacteria) of the Salton Sea under the No Action Alternative of the Nepa process.
Currently significant or abundant species indicated by shading.

Salinity Range (g/L)	Primary Producers (algae)	Consumers (invertebrates)	Consumers (fish)
40-50	**Thalassionema nitzschioides (diatom)**	**Neanthes succinea (polychaete)**	**Oreochromis mossambica (tilapia)**
	Cycotella sp. (diatom)	**Balanus amphitrite (barnacle)**	**Anisotremus davidsonii (sargo)**
	Pleurosigma ambrosianum (diatom)	Trichocorixa reticulata (water boatman)	**Bairdiella icistia (Gulf croaker)**
	Chaetoceros muelleri (diatom)	**Gammarus mucronatus (amphipod)**	**Cynoscion xanthulus (orangemouth corvina)**
	Tryblionella punctata (diatom)	**Synchaeta sp. (rotifer)**	**Cyprinodon macularius (desert pupfish)**
	Cylindrotheca closterium (diatom)	**Brachionus rotundiformis (rotifer)**	Mugil cephalus (mullet)
	Gyrodinium uncatenum (dinoflagellate)	**Apocyclops dengizicus (copepod)**	**Poecilia latipinna (sailfin molly)**
	Heterocapsa niei (dinoflagellate)	protozoans (mostly ciliates)	**Gillichthys mirabilis (longjaw mudsucker)**
	Scrippsiella trochoidea (dinoflagellate)		
	Prorocentrum minimum (dinoflagellate)		
	Gonyaulax grindleyi (dinoflagellate)		
	Oblea sp. (dinoflagellate)		
	Chattonella marina (raphidophyte-toxic?)		
	Pfiesteria -like (toxic)		
	Cryptomonas sp. (flagellate)		
	Chroomonas sp. (flagellate)		
	Eutreptia lanowii (euglenoid)		
	Crucigenia rectangularis (green alga)		
	Pleurochrysis pseudoroscoffensis (coccolithophore-toxic?)		
	Chaetomorpha sp. (macro green alga)		
	Enteromorpha sp. (macro green alga)		
50-60	Chaetoceros muelleri (diatom)	Brachionus plicatus (rotifer)	Cyrpinodon macularius (desert pupfish)
	Nodularia spumigena (cyanobacteria)	Trichocorixa reticulata (water boatman)	Mugil cephalus (mullet)
	Eutreptia lanowii (euglenoid)	Gammarus mucronatus (amphipod)	Gillichthys mirabilis (longjaw mudsucker)
		protozoans	Oreochromis mossambica (tilapia)
		Apocyclops dengizicus (copepod)	Poecilia latipinna (sailfin molly)
60-80	Dunaliella sp (green alga)	Artemia franciscana (brine shrimp) *	? Gillichthys mirabilis (longjaw mudsucker)
	Coccochloris elebans (cyanobacteria)	Ephydra riparia (brine fly) *	? Cyrpinodon macularius (desert pupfish)
	Chaetoceros muelleri (diatom)	protozoans	
	Nodularia spumigena (cyanobacteria)	Apocyclops dengizicus (copepod)	
	Eutreptia ianowii (euglenoid)		
	Nitzschia longissima (diatom)		
>80	Dunaliella sp (green alga)	Artemia franciscana (brine shrimp)	none
	Coccochloris elebans (cyanobacteria)	Ephydra riparia (brine fly)	
	Photosynthetic sulfur bacteria	protozoans	

Footnote *- abundance inversely related to densities of fish if present.

Table 1.- Changes in the water chemistry, biology and use of the Salton Sea resulting from increased salinity and decreased depth.

Water Constituent or Characteristic	Increased Salinity	Decreased Depth	Biological Effect	Use of Salton Sea
temperature	Increased thermal capacity: water slower to warm in summer and slower to cool in winter	Potential increase in summer temps. decrease in winter minimum temp.	Wide temperature fluctuation may be restrictive to some species.	May restrict sport fishery directly or change timing of spawning. Effects on avian resources not known.
dissolved oxygen	Decreased solubility	Increased mixing of atmospheric oxygen in near-surface water and suspension of oxygen-demanding materials from bottom.	Reduces numbers of oxygen-breathing organisms. May increase number of sulfate-reducing bacteria and organisms that can utilize atmospheric oxygen.	Restrict fishery, possible increase in odor due to sulfides, would decrease fish abundance for birds.
pH	Decreased buffer ability as calcium carbonate solubility is reduced causing pH to rise.	not known	Wide pH fluctuation may be restrictive to some species. Photosynthesis may cause wide variation in diel pH due to lack of buffering.	
turbidity	May decrease solubility of some organic substances, increasing the turbidity.	Increased turbidity due to suspension of bottom material.	Reduced light penetration for photosynthesis, particularly for benthic algae.	Adverse effect to aesthetics, restrict sport fishery, could cause surface algal scum as algal blooms more surface dominated.
nutrients (nitrogen, phosphorus)	Causes changes in biological community and may greatly change the interaction of nutrients in algal and animal groups.	Greater rate of mobilization of nutrients released from bottom sediment.	Algal blooms increased; greater oxygen demands from decaying algae; greater secondary production by zooplankton;	Odor problems, restrict fishery and avian populations at lower salinity but could increase avian use at high salinity if zooplankton dominated by artemia and ephydra
trace elements	Generally reduces toxicity of some due to common ion interaction.	Increased mobilization from sediment to oxidized water column may increase availability, particularly for selenium.	Effect on biota uncertain. While toxicity may be reduced due to salt effects, oxidation may make some elements more available.	At lower salinites, increased trace element availability could decrease abundance of fish and birds.